Plasma Fueling and Pumping: Burn Fraction & Fueling Efficiency

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Fueling and pumping system functions

- to provide hydrogenic fuel to maintain the plasma density profile for the specified fusion power,
- to replace the deuterium-tritium (D-T) ions consumed in the fusion reaction,
- to establish a density gradient for plasma particle (especially helium ash) flow to the edge,
- to supply hydrogenic edge fueling for increased scrape off layer flow for optimum divertor operation,
- to inject impurity gases at lower flow rates for divertor plasma radiative cooling, wall conditioning, and for plasma discharge termination on demand.
- To exhaust He ash at the rate it is produced and DT at approximately the fueling rate at a pressure consistent with divertor operation.

Fueling program scope

- Gas fueling prototype for ITER
- Pellet fueling development
  - H, D, T, Ne, Ar, Xe cryogenic solid pellets
  - Size from ~0.5 mm to 10 mm
  - feed rates from single shot to 0.26 g/s (ITER)
  - speeds from 100 to ~4000 m/s
- US-related plasma fueling experiments:
  - ORMAK, ISX, PDX, DIII, PLT, TEXT, PBX, TFTR, JET, TORE SUPRA, DIII-D, GAMMA 10, LHD, MST (2001), NSTX (2002)
  - Particle control and fueling physics; example: outside, inside and vertical launch on DIII-D
- Disruption mitigation and impurity fueling development
- Fueling system design for ITER and FIRE

Burn Fraction Definition

ion particle balance: $$\frac{dn_i}{dt} = S_i - \frac{n_i^2 < \sigma v >}{2} - L_i$$

definition of burn fraction: $$f_b = \frac{S_i - L_i}{S_i}$$

assume: $$L_i = \frac{n_i}{\tau}$$

then for steady-state: $$f_b = \left[1 + \frac{2}{n\tau < \sigma v >} \right]^{-1}$$

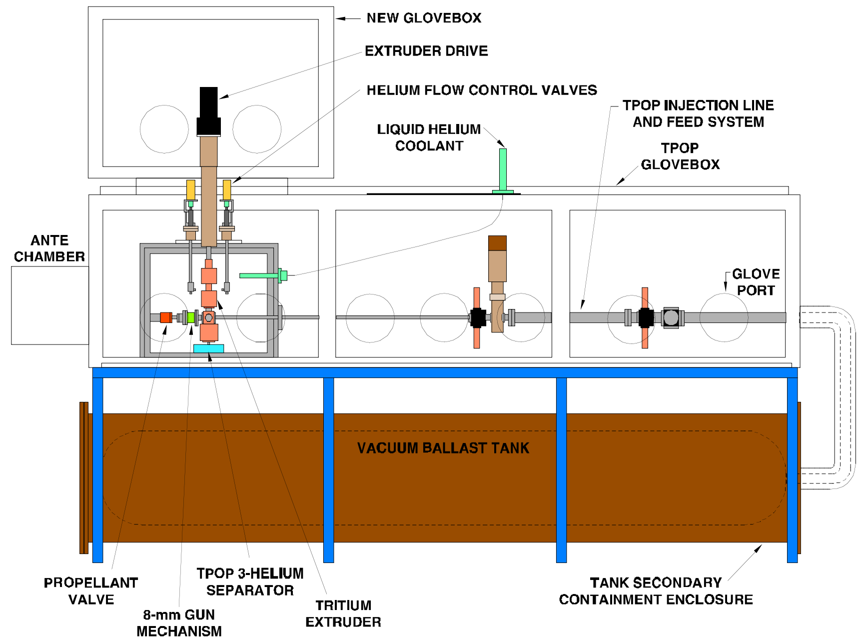
Burn Fraction Considerations

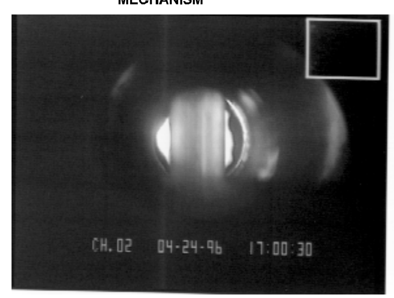
- For ITER-FEAT, the fueling system provides D-T plasma fueling at a steady-state rate of 200 Pa-m^3/s.
- The fuel rate to replace the D-T ions consumed by the fusion reaction is quite modest, about 1 Pa-m^3/s for a fusion power of ~750 MW.
- The resulting burn fraction is thus *only 0.5%* of the steady-state fueling rate.
- This is <u>much lower</u> than is typically used (assumed) in reactor studies: STARFIRE-42%, DEMO-10%, ARIES-1:19%
- A low burn fraction implies high D-T throughputs, large vacuum pumping and fuel processing systems with associated large tritium inventories and higher tritium breeding ratios.
- Ways to increase the burn fraction:
  - isotopic fueling,
  - efficient He ash exhaust without requiring large D/T flows,
  - others??

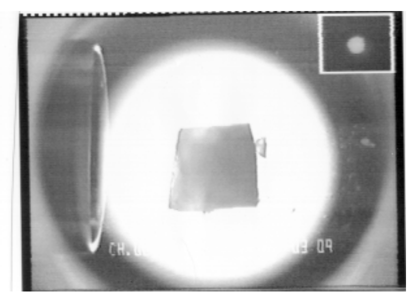
TPOP-II tritium extruder experiments

Highlights

- Demonstrated first extrusions of solid tritium at Tritium Systems Test Assembly Facility at LANL;
- Produced world’s largest pellets: 10 mm D, DT and T pellets (full scale for ITER);
- Processed over 40 grams of tritium through TPOP-II;
- Developed isotopic fueling concept to reduce ITER tritium throughputs and inventory.

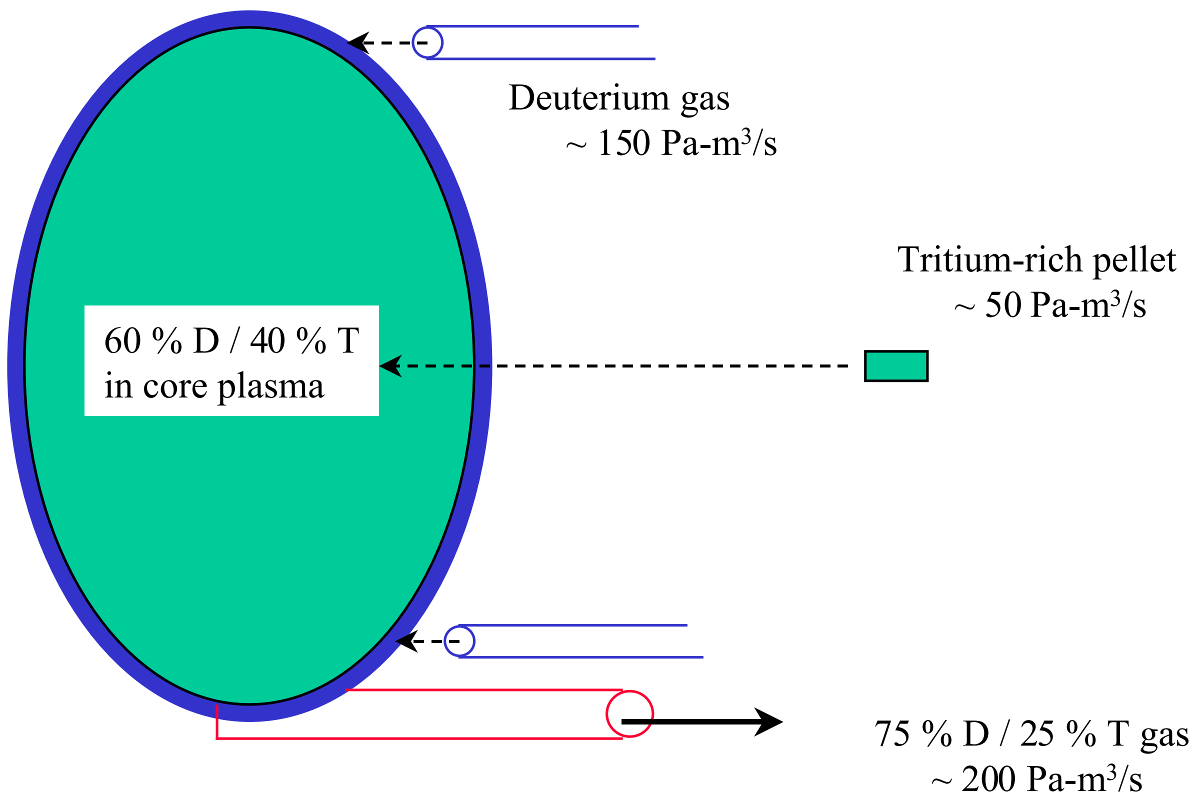






Isotopic Fueling:

- minimize tritium introduced into torus
- but maintain P_{fusion} (fuel rates shown typical of reactor)



Isotopic fueling model results are promising

- Isotopic fueling provides a radial gradient in the T and D densities.
- The magnitude of the effect depends on the separation of the two fueling sources.
- In-vessel tritium throughputs and wall inventories can be reduced by about a factor of two or more.
- This can ease requirements on the tritium breeding ratio.
- M. J. Gouge et al., *Fusion Technology*, **28**, p. 1644, (1995)

Figure 1

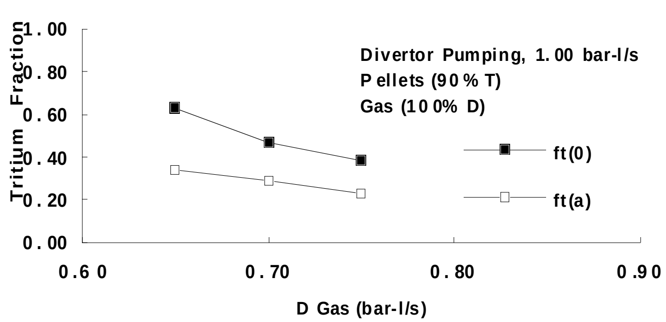
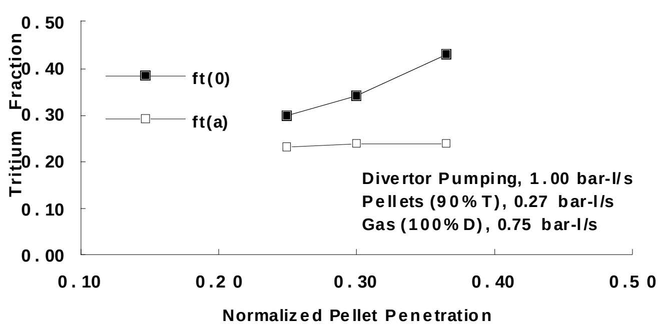


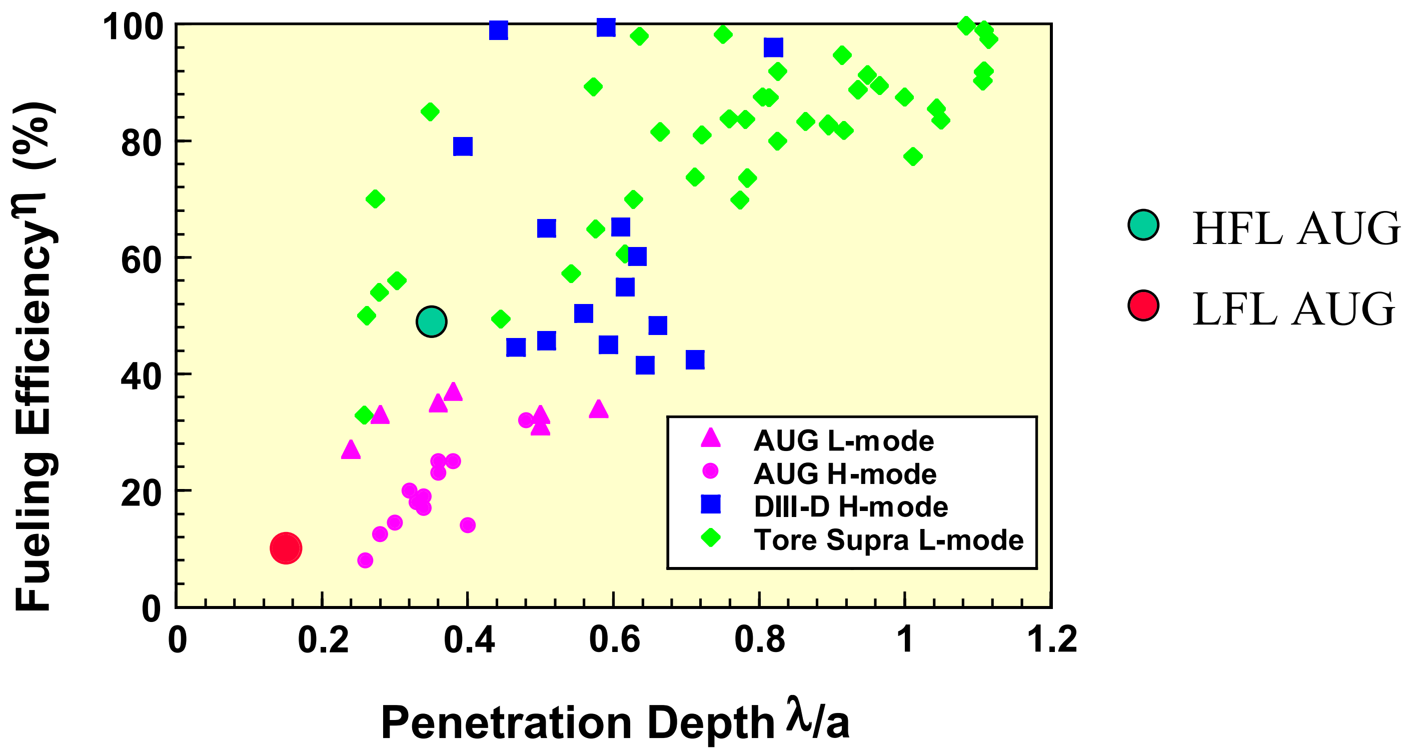
Figure 2



Efficiency of gas fueling much less than pellet fueling

Device	Gas Fuelling Efficiency (%)	Pellet Fuelling Efficiency (%)	Remarks
ASDEX	20	30-100	high density
PDX	10-15		high density
Tore Supra	1	30-100	ergodic divertor for gas fuelling
JET	2-10	20-90	active divertor
JT-60			
JT-60U			
TFTR	15		low density DT
ASDEX-U		8-40	
DIII-D	10	40-100	active divertor

Pellet fueling efficiency has a broad range



- Encouraging initial high field launch experiments on ASDEX-U
    - implications for FIRE
    - ongoing experiments on ASDEX-U, DIII-D, Tore Supra, JET, LHD

Fueling Conclusions

- Innovation and R&D in plasma fueling systems continues to positively impact future MFE devices
  - isotopic DT fueling: reduced tritium throughput, wall inventories
  - high-field-side launch: increased fueling efficiency, profile peaking for approach to ignition and high-Q burn